Claims

[c1] An apparatus for removing material adhering to a workpiece using the interface of a process liquid and an adjacent discontinuous phase comprising:a process tank having an interior designed to receive at least one workpiece, the process liquid, and the discontinuous phase;means for energizing the interface with megasonic energy; andmeans for producing relative movement between the interface and the workpiece at a controlled rate when the interface contacts the workpiece.

[c2] An apparatus as recited in claim 1, wherein the means for producing relative movement between the interface and the workpiece is also a means for moving the process liquid into and out of the interior of the process tank.

[c3] An apparatus as recited in claim 1, further comprising automatic process control means connected to the means for energizing the interface and the means for producing relative movement.

[c4] An apparatus as recited in claim 1, further comprising means for forming a gas-tight seal about the interior of the process tank, and means for varying the pressure at the interior of the process tank.

[c5] An apparatus as recited in claim 2, further comprising means for independently moving a plurality of process liquids into and out of the interior of the process tank.

[c6] An apparatus as recited in claim 1, further comprising means for removing a portion of the process liquid from the process tank as an overflow liquid.

[c7] An apparatus as recited in claim 6, further comprising a home container connected to the process tank and means for recirculating the overflow liquid to the home container.

[c8] An apparatus as recited in claim 1, further comprising means for maintaining the process liquid temperature at a predetermined value.

[c9] An apparatus as recited in claim 6, wherein the process liquid contains

entrained particles, further comprising means for using megasonic energy to propel the entrained particles into the overflow liquid.

[c10] An apparatus as recited in claim 2, further comprising means for introducing a gas into the process liquid for absorption into the process liquid.

[c11] An apparatus for removing material adhering to a workpiece using the interface of a process liquid and an adjacent discontinuous phase comprising:a process tank having an interior designed to receive at least one workpiece, the process liquid, and the discontinuous phase;means for energizing the interface with megasonic energy; and means for producing relative linear movement between the interface and the workpiece in alternating directions at a controlled rate.

[c12] An apparatus as recited in claim 11, further comprising means for forming a gas-tight seal about the interior of the process tank, wherein the means for producing relative movement between the interface and the workpiece further comprises a home container connected to the process tank, pressure-varying equipment connected to one or both of the process tank and the home container, level switches attached to the process tank and the home container, and an automatic process control connected to the level switches, the equipment for varying pressure in the home container or the process vessel and the means for energizing the interface.

[c13] An apparatus as recited in claim 11, further comprising means for forming a gas-tight seal about the interior of the process tank, wherein the means for producing relative movement between the interface and the workpiece further comprises a home container connected to the process tank, pressure-varying equipment connected to one or both of the process tank and the home container, means for determining when to alternate direction of relative movement, and an automatic process control connected to the pressure-varying equipment, the means for energizing the interface and the means for determining when to alternate direction of relative movement.

[c14] An apparatus as recited in claim 12, further comprising a plurality of process liquids, each process liquid having a home container connected to the process

tank, and means for dependently moving each of the process liquids from its home container into and out of the process tank.

[c15] An apparatus as recited in claim 11, further comprising means for removing a portion of the process liquid from the process tank as an overflow liquid.

[c16] An apparatus as recited in claim 15, further comprising a home container connected to the process tank and means for recirculating the overflow liquid to the home container.

[c17] An apparatus as recited in claim 11, further comprising means for maintaining the process liquid temperature at a predetermined value.

[c18] An apparatus as recited in claim 15, wherein the process liquid contains entrained particles, further comprising means for using megasonic energy to propel the entrained particles into the overflow liquid.

[c19] An apparatus as recited in claim 11, further comprising means for introducing a gas into the process liquid for absorption into the process liquid.

[c20] A method for removing material adhering to a workpiece, comprising the steps of: A) creating an interface between a process liquid and a discontinuous phase; B) energizing the interface with megasonic energy; C) contacting the workpiece with the energized interface and moving the energized interface relative to the workpiece at a controlled rate; and D) repeating step (C) a predetermined number of times, alternating the direction of relative movement with each repetition of step (C).

[c21] The method recited in claim 20, wherein the workpiece does not move during steps (C) and (D).

[c22] The method recited in claim 21, and wherein the interface remains fully energized between successive sweeps.

[c23] The method recited in claim 20, wherein the workpiece is completely separated from the process liquid after the final repetition of step (C).

[c24] The method recited in claim 23, further comprising the step of drying the

workpiece concurrently with or immediately following the final repetition of step (C).

[c25] The method recited in claim 24, wherein the process liquid is deionized water or dilute SC-1 at a temperature between 30 and 90 degrees Celsius, and the drying step comprises exposing the workpiece to a purge gas until the process liquid evaporates from the workpiece.

[c26] The method recited in claim 24, wherein the drying step further comprises condensing a vaporized second chemical on the workpiece and in the liquid interface, and mixing the second chemical with the process liquid in the liquid interface during separation of the workpiece from the process liquid.

[c27] The method recited in claim 24, wherein the drying step further comprises wetting a misted second chemical on the workpiece and in the liquid interface, and mixing the second chemical with the process liquid in the liquid interface during separation of the workpiece from the process liquid.

[c28] The method recited in claim 24, wherein process liquid is at a temperature slightly above its freezing point and initially at a pressure above its sublimation point, and the discontinuous phase is at a temperature below the freezing point of the process liquid, the drying step further comprising freezing the process liquid onto the workpiece as it is withdrawn from the process liquid, followed by removing the remaining process liquid and lowering the pressure of the discontinuous phase to sublime the frozen process liquid.

[c29] The method recited in claim 24, further comprising introducing a gas into the process liquid during step (D) for reducing the formation of droplets on the workpiece during the drying step.

[c30] A method for removing material adhering to a workpiece, comprising the steps of:A) creating an interface between a process liquid and a discontinuous phase;B) energizing the interface with megasonic energy;C) contacting the workpiece with the energized interface and moving the energized interface relative to the workpiece at a controlled rate; andD) repeating step (C) a predetermined number of times, alternating the direction of relative movement

with each repetition of step (C);wherein step (D) is performed without spraying the workpiece.

[c31] A method as recited in claim 30, wherein both step (C) and step (D) are performed without spraying the workpiece.